Medical Holography for Basic Anatomy Training

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ABSTRACT

The conceptualization of three-dimensional (3D) images within the human brain is a difficult task requiring extensive use of the brain's working memory. In the medical education community, this problem is particularly prevalent due to the complex 3D structures inherent in human anatomy. One potential solution to this problem is to present medical content in three dimensions rather than 2/2.5 dimensions. In doing so, the trainee would no longer be burdened with the additional cognitive load imposed during conversion of a 2/2.5D representation to a 3D representation within working memory. A unique technological solution to achieve this uses holography to present the medical content. Holography allows the user to view fully parallax, auto-stereoscopic 3D images. Within this research effort, static, full-color holograms were created depicting medical content. A study was conducted involving two groups of students presented with medical content in either a traditional format via textbook handouts or through holography. Cognitive load analysis was performed to determine if a difference in cognitive effort was experienced while using holography. A usability study was conducted to evaluate hologram performance and collect user experience metrics during the trial. This paper will discuss in detail the results of the experiment including the cognitive load analysis, the usability evaluation, performance trends, and lessons learned.

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Matthew Hackett is a science and technology manager for the Medical Simulation Research Branch of the Army Research Laboratory, Human Research and Engineering Directorate, Simulation and Training Technology Center. He manages a variety of projects including the medical holography research and virtual patient research efforts. As a science and technology manager, he oversees these research efforts and conducts test and evaluation to determine their efficacy in the simulation and training domain. Prior to his work with ARL, Mr. Hackett trained to be a government engineer while working as an engineering intern at the Program Executive Office for Simulation, Training and Instrumentation and worked within PM Training Devices.

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INTRODUCTION

The realm of simulation and training has rapidly advanced through the use of technology and the application of instructional design. Scientists and engineers are developing additional technological capabilities, while psychologists are researching more efficient training methods. The leaps in simulation based training are evident in the flight simulation realm, evolving from the Link flight simulator in World War II to the 6-axis high-fidelity flight simulators currently used. While many fields have readily adopted simulation into training, the medical field was initially quite reluctant. However, recent studies have shown that incorporation of simulation improves training outcomes (Okuda et al., 2009) and more medical schools are making simulation a core component of their curriculum (Passiment et al., 2011). With this paradigm shift, additional research avenues are opening to apply novel technologies within medical education.

One particular area of medical education which could benefit from new technological solutions is anatomy training. Anatomy training is a highly complex task, with multiple underlying learning objectives. Learning anatomy requires memorization of a vast array of anatomical structures, including bones, blood vessels, muscles, and nerves. Exacerbating the difficulty, the majority of the structures have complex nomenclature with roots in the Latin language, presenting learners with an entirely new vocabulary to learn. Lastly, the spatial relationships of anatomical structures are vital to understanding their form and function. The last factor is particularly challenging, forcing learners to expend a great deal of mental effort to understand the complex spatial orientation of the human body. Numerous studies have supported the supposition that the conceptualization of three-dimensional (3D) anatomy is challenging for students (Cottam, 1999; Miller, 2000; Garg et al., 2001; Dev et al., 2002). Demonstrating the difficulty of anatomical learning, self reported surveys showed a majority of residency directors reported incoming medical residents needed a refresher in anatomy training (Cottam, 1999).

The application of visualization technologies has the potential to solve many of the issues challenging anatomy students. Computerized representations of anatomy is a research area that advanced with technology for many years, first focusing on the generation of 3D anatomical models, creation of databases to store the knowledge, and integration of these models into training programs (Rosse, 1995). Recent studies have improved 3D visualizations of anatomical structures using Quicktime Virtual Reality formats (Silen et al., 2008; Petersson et al., 2009). These studies both showed improvements in student interest and suggest beneficial effects on learning due to the use of advanced 3D visualizations. Additional research focused on factors surrounding the use of 3D visualizations, with a key finding showing that spatial ability plays a large role in learning spatial anatomy (Garg et al., 2001). The scheme for presentation and manipulation of 3D visualizations is important; student controlled visualizations with multi-view capability yield improvements in learning over automatically rotating visualizations (Garg et al., 2002). Studies in 3D visualization using the complex structures of the inner ear (Nicholson, 2006) and the carpal bones (Garg et al., 2001) showed improvements in anatomical knowledge and spatial learning. These studies demonstrate that properly applied 3D anatomical models can aid in anatomy education. Extending these findings to an emerging visualization technology, this paper examines the use of 3D medical holograms for anatomy training. Cognitive load, usability metrics, and performance trends are discussed, along with avenues for future research.

HOLOGRAPHY

The term holography brings to mind science fiction, such as the Holodeck from Star Trek. While that capability is still out of reach, current holographic technology is able to present high quality auto-stereoscopic (no-glasses) 3D visuals. Holography began in the 1940s, when Dennis Gabor invented the hologram and won the Nobel Prize for the achievement (Gabor, 1948). Significant advances occurred when researchers created the first practical hologram using laser illumination (Denisyuk, 1962; Leith & Upatnieks, 1962). The ability to view holograms using simple white light further revolutionized the field (Leith, 1976), allowing holograms to begin to move out of the laboratory.

With advances in lasers and optics, the fidelity and feasibility of holograms continues to improve. A full discussion of holography, including analysis of the underlying optical theory, microscopy uses, and physics based discussions is published in numerous books (Benton & Bove, 2008; Collier & Burckhardt, 1971).

For this effort, the focus is upon a particular hologram variant called a digital hologram, developed during joint research by Defense Advanced Research Projects Agency (DARPA), Army Research, Development, and Engineering Command (RDECOM), and industry partners. The digital holograms are reflective auto-stereoscopic static imagery presentations allowing for 3D visualizations without glasses. The digital holograms contain holographic elements (hogels) rather than pixels or voxels, with a hogel size of 1mm. Each hogel contains up to one million different perspective views, resulting in digital holograms having full image parallax (Havig et al., 2005). These digital holograms are currently in use within the military, primarily for route planning, mission rehearsal, and terrain visualization. Studies by the Air Force Research Laboratory (AFRL) and RDECOM showed that the use of digital holograms improved time and accuracy in identifying tactical and terrain-related features when compared to conventional 2D maps and imagery. Additional benefit was reported in situational awareness, planning, and decision making (Kalphat & Martin, 2009). Performance based metrics on route planning done using SWAT team members found that using the hologram resulted in significantly faster generation of routes (Fuhrmann et al., 2012). The use of eye-tracking metrics, specifically saccade / fixation ratio, fixation duration, and saccade length, revealed that using a 3D digital hologram improved information processing efficiency during route planning (Fuhrmann, 2009). The successes of these studies in route planning and the improvements in information processing support the notion that other fields, such as medical education, architecture, or civil engineering, might benefit from the use of holographic technology.

COGNITIVE LOAD

The presentation of information is vital in all forms of education. Changing the way information is presented can be beneficial to the learner, and the amount of benefit can be measured through the lens of cognitive load. Cognitive load is the load imposed upon the working memory by executive processes. Cognitive Load Theory (CLT) relies on the model of human information processing, which occurs through three types of memory: sensory memory, working memory, and long-term memory. Sensory memory originates from sensory organs, such as the eyes and ears, and lasts only a few seconds. Working memory provides processing of the information from sensory memory. Working memory has significant limitations in terms of size and duration (Simon, 1974) holding only seven items or elements at a time (Milller, 1956). The brain moves the information from working memory into long-term memory through the use of organizational schemas, which categorize the information in the manner it will be used (Chi, Glaser, & Rees, 1982). Other research discusses this information organization conceptually as chunks (Miller, 1956) or scripts (Schank & Abelson, 1977); however, they are functionally the same concept.

In order to optimize the presentation of information, CLT targets the working memory process where cognitive load exists. The central tenet of CLT is that working memory can be overloaded with information, resulting in decreased learning performance. Conversely, by reducing cognitive load, additional learning processes can occur. Within CLT, cognitive load is split into three sub-components: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Sweller, 1988, 1989). Intrinsic cognitive load relates to the inherent characteristics of the content (Sweller & Chandler, 1994), such as the number of elements or element interactivity. Studies show that instruction design changes cannot alter intrinsic cognitive load (Ayres, 2006; Paas, 2003). For example, intrinsic load during anatomy training results from a high amount of information, but a relatively low interaction between the learning elements (Sweller, 1998). As a result, learning the names of individual muscles, bones, nerves, etc., does not impose a high cognitive load, but manipulating these into usable units for understanding spatial and functional relationships results in extensive intrinsic cognitive load (Khalil et al., 2005).

Germane load focuses on converting the information within working memory into schemas for storage in long term memory. Germane load is incredibly important because it directly relates to learning processes, including the construction of schemas and the automation of schemas (van Merrienboer, 2002). The tasks involved in the construction of schemas include interpreting, exemplifying, classifying, inferring, differentiating, and organizing information (Mayer, 2002). The goal of instructional designers is to encourage these learning processes to the utmost extent.

The final component of cognitive load is extraneous cognitive load. Extraneous load is load not related to learning and can be altered by instructional interventions (van Merrienboer & Sweller, 2005). The vast majority of research focuses on reducing extraneous cognitive load within information presentations. The goal of reducing extraneous cognitive load is ultimately to reduce time and mental resources wasted during processing of excess information. The combination of extraneous load, germane load, and intrinsic load comprise overall cognitive load; when the cognitive load imposed exceeds the capacity of the working memory, cognitive overload occurs (Figure 1). The presentation of medical holograms may impact both germane and extraneous processes.

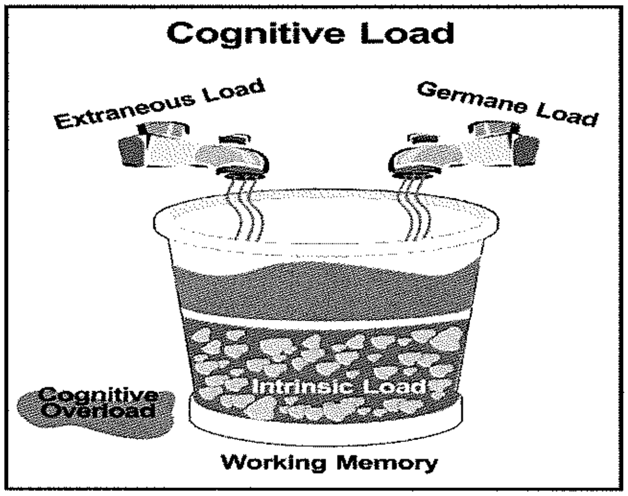

Figure 1: Cognitive Load Overview: The bucket represents the brain's working memory. The rocks represent intrinsic load, the unchanging portion of cognitive load. The water represents germane and extraneous load, the portion changed by information presentation. When working memory "overflows", cognitive overload occurs.

METHODOLOGY

The experimental design split the participants into two groups: a control group received anatomical handouts and a treatment group received medical holograms. A total of 19 volunteers participated in the study, with 9 in the control and 10 in the treatment group. The medical content focused on cardiac anatomy, with an emphasis on heart valves and surrounding vascular structures. The medical hologram presented four views of the heart: full view, full view with labels, cutaway view, and cutaway view with labels. The hologram was channeled, with participants rotating the hologram 90° to move between views (Figure 2). The medical handouts showed the same four views and labels. The handouts were stapled together in a booklet to ensure that the control group experienced the content one view at a time.

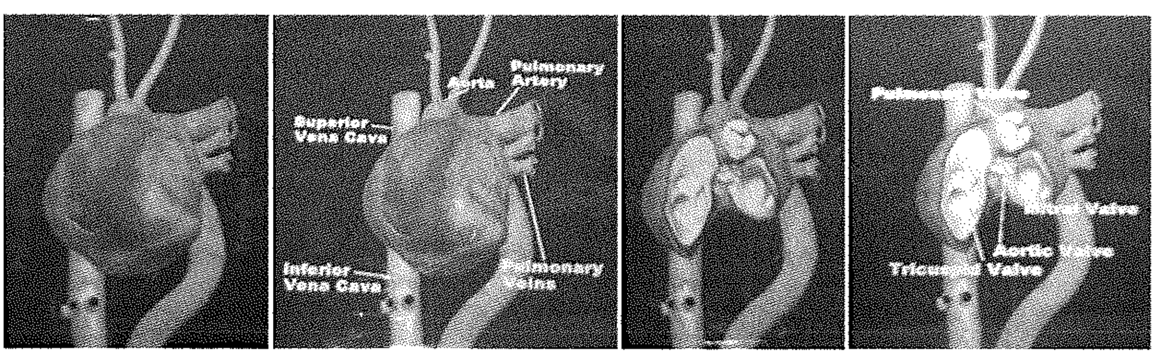

Figure 2: Four views of the heart in the channeled medical hologram

Each participant completed a pre-test on cardiac anatomy prior to exposure to the treatment. Then, the participants received the medical content in an isolated, quiet room with instructions to study the material for five minutes. Following the study period, participants completed a post-test with same questions as the pre-test presented in a different order. After post-treatment testing, participants reported their perceived cognitive load on a nine-point rating scale indicating their "perceived amount of mental effort" ranging from "very very low mental effort (1) to very very high mental effort (9)" (Paas, 1992). This instrument is the most commonly used for measurement of cognitive load (de Jong, 2010) and is reliable with a reported Cronbach's α of .9 and .82 from two separate studies (Paas et al., 2003). The instrument is shown in figure 3. The holograms treatment group also filled out a survey regarding the spatial utility of the holograms and general user experience. The survey was 13 questions using a 1-5 Likert scale ranging from strongly disagree to strongly agree.

Please rate your mental effort during this task.								
1 Very very low mental Effort	2	3	4	5 Neither low nor high mental effort	6	7	8	9 Very very high mental effort

Figure 3: Nine-point rating scale for cognitive load measurement

RESULTS

Performance Results

The results show similar performance on the pre-test for the control group ($M = 36.67$; $SE = 6.0$) and the hologram treatment group ($M = 47.0$; $SE = 5.97$). The difference between the two was not significant $t(17) = -1.217$; $p > .05$. These results indicate both groups had the same amount of preliminary knowledge in cardiac anatomy. Both treatment groups showed significant improvement from pre- to post-test. On average, participants exposed to the medical holograms showed superior post-test performance ($M = 89.0$, $SE = 3.48$) when compared to participants exposed to handouts ($M = 67.78$, $SE = 6.186$). The difference between these two groups was significant $t(17) = -2.990$, $p < .05$ (Figure 4). The effect size was .64, representing a large-sized effect.

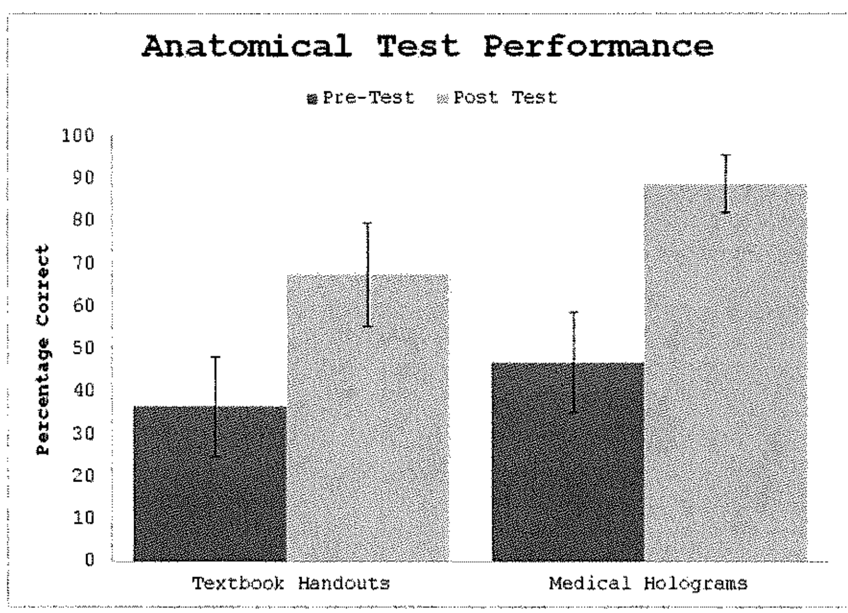

Figure 4: Comparison of Textbook Handouts and Medical Holograms Performance (95% CI shown)

A more in depth analysis of the performance split the questions into two categories: nomenclature / general anatomical knowledge and spatial knowledge. In both areas, the medical holograms treatment showed significant

improvements over the textbook handouts. For nomenclature / general anatomical knowledge, the medical hologram treatment performed better (*M = 95.0, SE = 3.33*) than handouts (*M = 75.0, SE = 8.33*) by a statistically significant margin $t(17) = -2.317$, $p < .05$. Similar results were seen in spatial questions, where the holograms treatment (*M = 84.7, SE = 4.7*) outperformed the handouts treatment (*M = 62.67, SE = 9.15*) by a significant amount $t(17) = -2.2$, $p < .05$ (Figure 5).

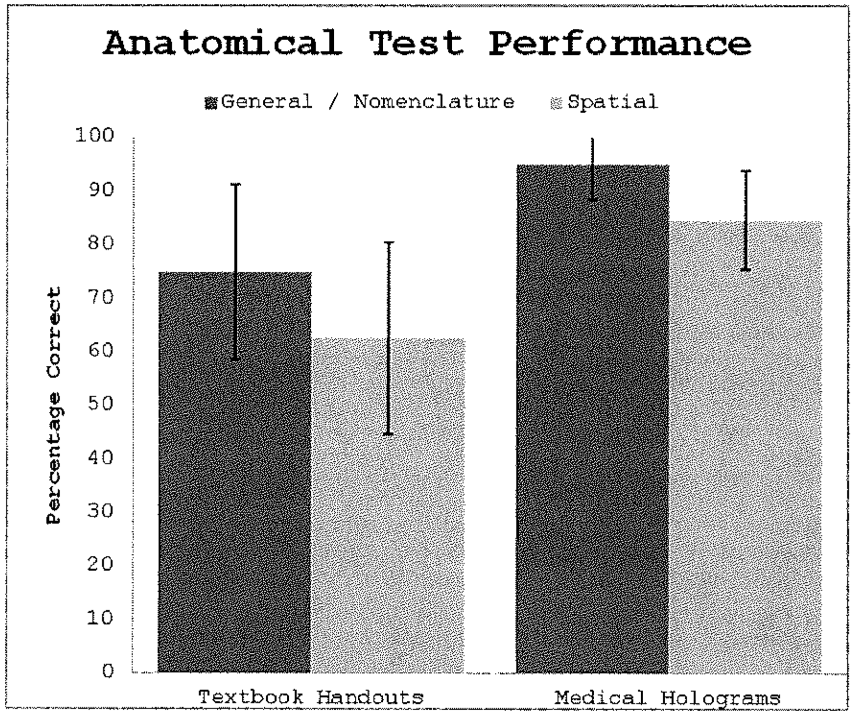

Figure 5: Comparison of Medical Holograms and Handouts on Specific Question Type (95% CI shown)

Cognitive Load Analysis Results

The cognitive load measure showed that holograms resulted in decreased cognitive load. The medical holograms (*M = 4.9, SE = .48*) had lower self-reported mental effort than textbook handouts (*M= 6.0, SE = .577*). The difference was not significant $t(17) = 1.463$, $p = .163$. The trend does suggest that the use of holograms for anatomy training results in decreases in cognitive load, but within this study cannot be conclusively determined.

An additional metric which is highly relevant to cognitive load is efficiency of instructional conditions. This metric is a construct of performance and mental effort. By converting cognitive load measures and performance measures into z scores, researchers can compare the relative efficiency between treatments (Paas, 1993). Treatments with lower mental effort and higher performance are considered more efficient than treatments with lower performance and higher mental effort. Results are graphed where the X-axis is mental effort and the Y-axis is performance. The efficiency of each condition is plotted and compared with a line E=0 representing zero efficiency. The efficiency value E is the distance from the E=0 line to the treatment point. The equation for this is shown in equation 1, where P is the mean performance z-score and R is the mean mental effort z-score.

$$E = (P - R)/\sqrt{2} \quad (1)$$

The efficiency results indicated that the holograms treatment was highly efficient, with a mean performance z-score of 0.55 and a mean mental effort z-score of -0.31. The efficiency of the medical holograms was 0.61 using eq. 1. The efficiency of the medical handouts showed low efficiency, with a mean performance z-score of -0.61 and a mean cognitive z-score of 0.34. The efficiency of the handouts was -0.677. The results are shown on an efficiency plot in figure 6.

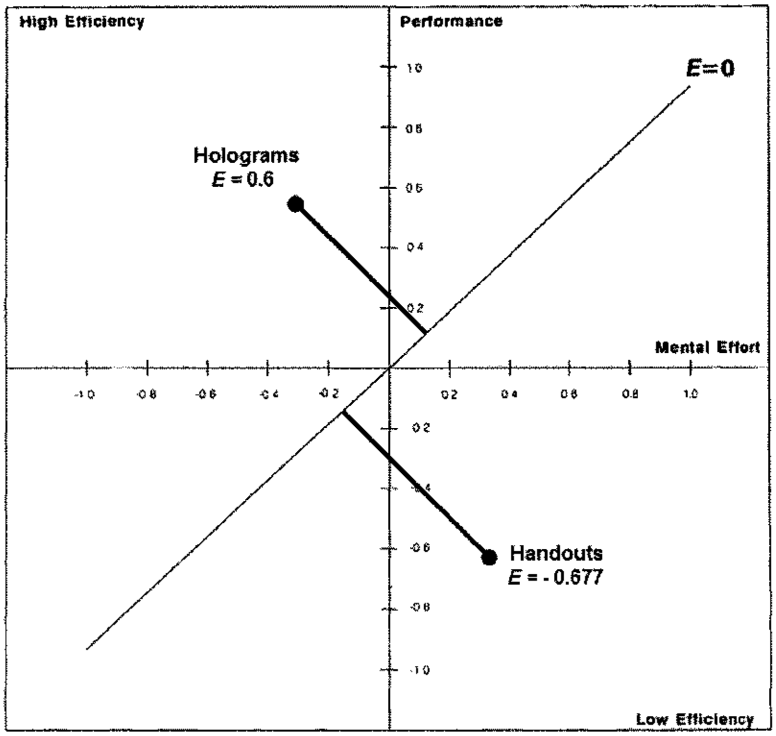

Figure 6: Efficiency of Medical Hologram and Textbook Handout Conditions

Usability Results

The participants in the holographic study responded favorably to the technology as indicated by the results of the usability survey. The average score was 4.3 out of 5, which indicated a very positive experience overall. The spatial questions had an average score of 4.08, indicating that users were able to gather the pertinent 3D spatial data. The user experience questions focused on ease of use and user frustration, and had an average score of 4.48, suggesting that users were satisfied and felt the holograms were useful (Figure 7).

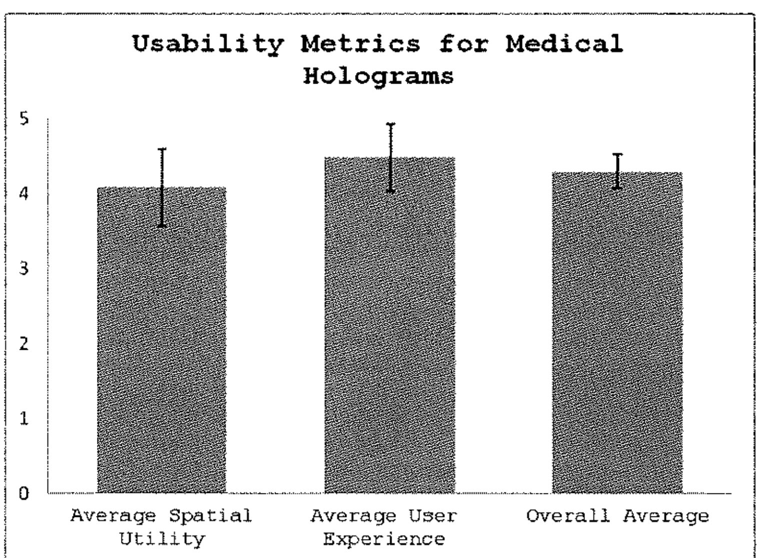

Figure 7: Usability Metrics for Medical Holograms (95% CI shown)

CONCLUSIONS

The medical holograms treatment presents a significant performance improvement over traditional textbook handouts. There are a number of possible reasons for this improvement. The first is the "wow-factor". Textbook handouts are very commonplace and elicit little inherent interest subsequently. The medical holograms are a novel technology, which may have garnered additional interest and focus from participants; this inherent curiosity with the technology may have caused them to study the material more intently.

The next possibility relates to a particular learning strategy known as imagery strategy. Imagery strategies involve creating a memory by taking what is learned and creating meaningful visual or auditory mental images of the information (Muskingum University, 2013). The creation of such a mental image would fall into the germane load and would be a direct process towards learning. The medical holograms have the advantage of being natively 3D, unlike textbook handouts. As such, the medical holograms may be directly translated to a mental image, while a 2D textbook handout requires 3D reconstruction within the working memory. The resulting mental images from the medical holograms may be superior to textbook handouts due to their immediate translation into working memory.

Finally, the medical holograms may simply provide superior visual capabilities due to their 3D nature. Many anatomical structures are difficult to conceptualize, such as the spatial relationships between various blood vessels, the valves of the heart, and the chambers of the heart. Medical holograms provide additional 3D data to understand these relationships, such as depth cues. The concept of visual grouping suggests that 3D perception relies on grouping visual subcomponents based on textures, color gradients, and continuity of structures (Buhrmann et al., 1999). The additional dimension present in medical holograms may have provided information that was either not present or difficult to process in the textbook handouts. This additional information may have also aided in the creation of visual groups allowing for improved processing of the anatomical content.

The cognitive load measurement showed trends which indicate that the medical holograms may result in decreased cognitive load. The benefits of decreased cognitive load include improved learning outcomes and the ability to utilize the working memory for other cognitive tasks. By freeing resources in the working memory, learning in other areas may improve. Another possible result is that the freed resources may be reallocated to focus more upon germane load processes, such as organizing information into long term memory. While cognitive load is important, the efficiency metric includes performance metrics into its calculation, providing a more thorough metric for assessing instructional utility. The efficiency metric showed trends of high efficiency for the medical holograms. In this case, the medical holograms provided an excellent mix of relatively low cognitive load with high performance. Conversely, the medical handouts showed low efficiency, with a relatively high cognitive load and low performance.

The usability results indicate that the overall user opinion of the holograms is very promising. All users were able to see all the intended views and were able to easily use the holograms. No users reported any issues regarding eye strain or difficulty reading the labeling. These early usability trends indicate that on a larger scale, the user acceptance of a technology may be high.

The results of the experiment indicate the medical holograms may be a beneficial tool in the challenge field of anatomical education. Future work is necessary to validate the results of this early experiment, including a larger sample size and additional content areas. Other technologies for visualizing anatomy in 2.5/3D would serve as excellent comparison studies, such as 2.5D representations on tablets or computer screens. This would give a broader understanding of the utility of 2.5/3D anatomical representations for education. Additional measures of cognitive load should also be utilized, such as dual task analysis and physiological measures. These additional measures will be analyzed in relation to the cognitive load metrics gathered from self-reporting, ensuring both data sets indicate similar trends. Finally, a technology acceptance study for the medical holograms, focusing on perceived usefulness and perceived ease of use, would be beneficial to determine how readily medical practitioners and students would accept a novel technology into curriculum. Based upon the results, the medical holograms showed improved anatomical learning, may reduce cognitive load during anatomical education, and warrant additional research to fully understand their potential benefits.

REFERENCES

Ayres, P. (2006). Using subjective measures to detect variations of intrinsic cognitive load within problems. Learning and Instruction, 16(5), 389-400.

Benton, S. A., & Bove Jr, V. M. (2008). Holographic imaging. Wiley-Interscience.

Buhmann, J. M., Malik, J., & Perona, P. (1999). Image recognition: Visual grouping, recognition, and learning. Proceedings of the National Academy of Sciences, 96(25), 14203-14204.

Chi, M. T., Glaser, R., & Rees, E. (1981). Expertise in problem solving (pp. pp-7). Pittsburgh: Learning Research and Development Center, University of Pittsburgh.

Collier, R. J., Burckhardt, C. B., & Lin, L. H. (1971). Optical holography. New York: Academic Press, 1971, 1.

Cottam, W. W. (1999). Adequacy of medical school gross anatomy education as perceived by certain postgraduate residency programs and anatomy course directors. Clinical Anatomy, 12(1), 55-65.

de Jong, T. (2010). Cognitive load theory, educational research, and instructional design: some food for thought. Instructional Science, 38(2), 105-134.

Denisyuk, Y. N. (1962, December). Photographic reconstruction of the optical properties of an object in its own scattered radiation field. In Soviet Physics Doklady (Vol. 7, p. 543).

Fuhrmann, S., Komogortsev, O., & Tamir, D. (2009). Investigating Hologram-Based Route Planning. Transactions in GIS, 13(s1), 177-196.

Fuhrmann, S., Smith, N. J., Holzbach, M., & Nichols, T. (2012). Investigating Geospatial Holograms for Special Weapons and Tactics Teams. Cartographic Perspectives, (63), 5-19.

Gabor, D. (1948). A new microscopic principle. Nature, 161(4098), 777-778.

Garg, A., Norman, G. R., Spero, L., & Maheshwari, P. (1999). Do virtual computer models hinder anatomy learning?. Academic Medicine, 74(10), S87-9

Garg, A. X., Norman, G., & Sperotable, L. (2001). How medical students learn spatial anatomy. The Lancet, 357(9253), 363-364.

Garg, A. X., Norman, G. R., Eva, K. W., Spero, L., & Sharan, S. (2002). Is there any real virtue of virtual reality?: The minor role of multiple orientations in learning anatomy from computers. Academic Medicine, 77(10), S97-S99.

Havig, P., McIntire, J., & McGruder, R. (2006, February). Analysis of an autostereoscopic display: the perceptual range of the three-dimensional visual fields and saliency of static depth cues. In Electronic Imaging 2006 (pp. 60550C-60550C). International Society for Optics and Photonics.

Kalphat, H. M., & Martin, J. J. (2009, January). Tactical Digital Holograms in Support of Mission Planning and Training. In The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC) (Vol. 2009, No. 1). National Training Systems Association.

Khalil, M. K., Paas, F., Johnson, T. E., & Payer, A. F. (2005). Interactive and dynamic visualizations in teaching and learning of anatomy: A cognitive load perspective. The Anatomical Record Part B: The New Anatomist, 286(1), 8-14.

Leith, E. N., & Upatnieks, J. (1962). Reconstructed wavefronts and communication theory. JOSA, 52(10), 1123-1128.

Leith, E. N. (1976). White-light holograms. Scientific American, 235, 80-88.

Mayer, R. E. (2002). Multimedia learning. Psychology of Learning and Motivation, 41, 85-139.

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. The psychological review, 63, 81-97.

Miller, R. (2000). Approaches to learning spatial relationships in gross anatomy: perspective from wider principles of learning. Clinical Anatomy, 13(6), 439-443.

Muskingum University. (n.d.). Learning Strategies Database – Visual Imagery. Retrieved May 13, 2013 from http://www.muskingum.edu/~cal/database/general/encoding5.html.

Nicholson, D. T., Chalk, C., Funnell, W. R. J., & Daniel, S. J. (2006). Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. Medical Education, 40(11), 1081-1087.

Okuda, Y., Bryson, E. O., DeMaria, S., Jacobson, L., Quinones, J., Shen, B., & Levine, A. I. (2009). The utility of simulation in medical education: what is the evidence?. Mount Sinai Journal of Medicine: A Journal of Translational and Personalized Medicine, 76(4), 330-343.

Paas, F. G., & Van Merriënboer, J. J. (1993). The efficiency of instructional conditions: An approach to combine mental effort and performance measures. Human Factors: The Journal of the Human Factors and Ergonomics Society, 35(4), 737-743.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. Educational psychologist, 38(1), 1-4.

Passiment, M., Sacks, H., Huang, G. (2011). Medical Simulation in Medical Education: Results of an AAMC Survey. Association of American Medical Colleges.

Petersson, H., Sinkvist, D., Wang, C., & Smedby, Ö. (2009). Web-based interactive 3D visualization as a tool for improved anatomy learning. Anatomical sciences education, 2(2), 61-68.

Rosse, C. (1995). The potential of computerized representations of anatomy in the training of health care providers. Academic Medicine, 70(6), 499-505.

Schank, R., Abelson, R., & Schank, R. C. (1977). Scripts Plans Goals. Lea.

Silén, C., Wirell, S., Kvist, J., Nylander, E., & Smedby, Ö. (2008). Advanced 3D visualization in student-centred medical education. Medical teacher, 30(5), e115-e124.

Simon, H. A. (1974). How big is a chunk. Science, 183(4124), 482-488.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive science, 12(2), 257-285.

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. Journal of educational psychology, 81(4), 457-466.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. Cognition and instruction, 12(3), 185-233.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. Learning and instruction, 4(4), 295-312.

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. Educational psychology review, 10(3), 251-296.

Van Merriënboer, J. J. G., Schuurman, J. G., De Croock, M. B. M., & Paas, F. G. W. C. (2002). Redirecting learners' attention during training: Effects on cognitive load, transfer test performance and training efficiency. Learning and Instruction, 12(1), 11-37.

Van Merriënboer, J. J., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. Educational psychology review, 17(2), 147-177.